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Greener energy: Issues and challenges for Pakistan-hydel power prospective

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ABSTRACT

Water is a vital resource that supports all forms of life on earth. Progressive release of greenhouse gases (GHG) from increasing energy-intensive industries has eventually caused human civilization to suffer. During the past two decades, the risk and reality of environmental degradation have become more apparent. Renewable Energy provides an effective option for the provision of energy services from the technical point of view while hydropower, a major source of energy in the, appears an important renewable source of energy, its viability for large-scale energy production. Hydropower is renewable, reliable, clean, and largely carbon-free, and represents a flexible peak-load technology. With most of the world's hydropower potential available for near future development, it is local interests and sovereign states that decide how to manage their water resource base. In Pakistan the availability of power had been continually falling short of the demand of 24,474 MW and as a result, the country is experiencing power shortages of varying degrees in different parts of the country. Geographically, Pakistan has been blessed with river flows that are naturally supportive to electricity generation. Considering the large potential and the intrinsic characteristics of hydropower in promoting the country's energy security and flexibility in system operation, government is tried to accelerate hydropower development through number of policy initiatives. This paper investigates the progress and challenges for hydel power generation in Pakistan according to the overall concept of sustainable development and identifies the region wise potential of hydel power in Pakistan, its current status. Barriers are examined and Policy issue and institutional roles and responsibilities are discussed.

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1. Introduction

The recently released report of the International Energy Outlook (IEO 2010) [1] projects an increase of 50% in the world energy demand from 2007 to 2035, and 87% rise in the net electricity generation worldwide in the same period. From 2007 to 2035, world renewable energy use for electricity generation grows by an average of 3.0 percent per year and the renewable share of world electricity generation increases from 18 percent in 2007 to 23 percent in 2035. Much of the world increase in renewable electricity supply is fueled by hydropower and wind power. Of the 4.5 trillion kilowatt-hours of increased renewable generation over the projection period, 2.4 trillion kilowatt-hours (54 percent) is attributed to hydroelectric power and 1.2 trillion kilowatt-hours (26 percent) to wind. Except for those two sources, most renewable generation technologies are not economically competitive with fossil fuels over the projection period, outside a limited number of niche markets.

Hydropower is renewable, reliable, clean, and largely carbon-free, and represents a flexible peak-load technology. Hydropower is available in a broad range of project scales and types. Projects can be designed to suit particular needs and specific site conditions. As hydropower does not consume or pollute the water it uses to generate power, it leaves this vital resource available for other uses. Hydropower often supports other essential water services such as irrigation, flood control and drinking water supplies. It facilitates the equitable sharing of a common vital resource. At the same time, the revenues generated through electricity sales can finance other infrastructure essential for human welfare. This can include drinking water supply systems, irrigation schemes for food production, infrastructures enhancing navigation, recreational facilities and ecotourism. Yuksel, 2010 [2] has discussed the Advantages and disadvantages of the hydropower option in details. However, on a local level, due to the site specificity, there is a wide spectrum of interactions involving the watercourses, the environment, the local communities and the resident population. Hydropower plants do not consume or pollute the water they use to run their turbines, but do have an impact on the environment through damming (inundation), diversion and/or hydro-peaking. Dams and weirs interrupt the flow of streams, and as a result can be responsible for environmental problems. Hydro-peaking and low flows are effects that occur downstream. Resettlement is one of the major problems in the context of hydropower and the compensation schemes reveal unsolved difficulties in practice. The alteration of water bodies, habitats and landscape, as well as the loss of land that occurs from electricity generation in hydropower schemes, also affects other businesses or branches of industries. These effects can be positive or negative, but the latter are at the heart of many conflicts of use. However the negative impacts mentioned could often be mitigated or avoided if they were considered early in the planning and construction process.

The Beijing Declaration on Hydropower & Sustainable Development agreed at the United Nations Symposium on Hydropower and Sustainable Development from October 27, 2004, to October 29, 2004, pledge the developing countries and undeveloped countries to pay considerable attention and prioritize the development of hydropower for poverty reduction, achieving the Millennium Development Goals (MDG), promoting the development of the economy and society and improving the environment. Declaration also reiterate that access to energy is essential to achieving sustainable development and is critical for meeting the MDGs and Johannesburg Plan of Implementation (JPOI) targets and commitments. Declaration emphasizes that improving access to energy will generate opportunities for economic growth, enhanced education, better health care, more training and employment, as well as higher productivity in business, thereby contributing to sustained poverty reduction.

The discrepancy in the available data highlights an issue currently challenging all renewable energies, and one that has important consequences for communicating the role of renewables such as hydro to key institutions and policymakers. International Hydropower Association (IHA) [3] has provided statistical figures normalized against available literature and industry information, more detailed and accurate statistical information essential to ensure that the role and importance of hydropower is adequately conveyed to key decision makers. Hydropower is a well established electricity system on the global scene. Hydropower is currently being utilized in over 160 countries. At end-2008, global installed hydropower capacity stood at about 874 GW. According to IHA, this capacity is derived from some 11,000 stations, with around 27,000 generating units [3]. One reason for hydropower's success is that it is a widespread resource—160 countries use hydropower to some extent. In several countries hydropower is the largest contributor to grid electricity—it is not uncommon in developing countries for a large dam to be the main generating source. Nevertheless Brazil, Canada, China, Russia and the United States currently produce more than half of the world's hydropower [4].

The physical principles of a hydropower plant are simple. The potential energy caused by gravity of water at an elevated level is transformed to water pressure (and some kinetic energy) as the water is lead through pipes from a water inlet down to a power station. In the power station this energy is first transformed to mechanical energy in a hydropower turbine and then to electricity in a generator. The amount of energy is decided by the flow of water and the elevation of the inlet. This principle is the basis for all kinds of hydropower stations (Fig. 1). The best turbines can have hydraulic efficiencies in the range 80 to over 90% (higher than most other prime movers), although this will reduce with size. Microhydro systems tend to be in the range 60–80% efficient [5]. The absolute limit on hydropower is the rate at which water flows downhill through the world's rivers, turning potential energy into kinetic energy as it goes. The amount of power that could

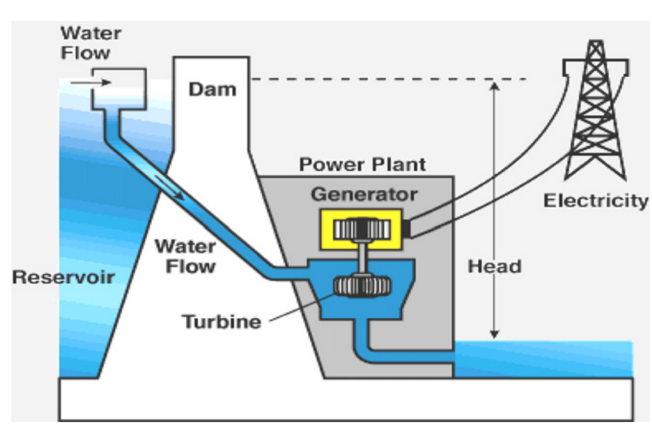

Fig. 1. Illustration of a hydropower plant [6].

theoretically be generated if the entire world's run-off were 'turbined' down to sea level is more than 10 terawatts. However, it is rare for 50% of a river's power to be exploitable, and in many cases the figure is below 30% [4].

Hydroelectric systems are unique among generating systems in that they can, if correctly engineered, store the energy generated elsewhere, pumping water uphill when energy is abundant. The reservoirs they create can also provide water for irrigation, a way to control floods and create amenities for recreational use [4].

In electric network, hydroelectricity is characterized by convenient start and stop of power generation, flexible operation at low cost, and assurance of the safe operation of electric network by means of peak and frequency modulation.

Developing hydroelectricity is in favor of pollution control and environment protection as well as higher rate of resource utilization and comprehensive economic benefit. However there are reports on some hydropower projects that adversely affected the society, environment and ecology, and so on, and attracted considerable attention worldwide. Yet, numerous successful and mature projects have proved that, when carefully planned and executed, hydroelectric development can be reliable, cheap, economical and environment friendly as well as in favor of social harmony. The improved access to clean modern energy in developing countries is a fundamental step to poverty reduction [7,8]. Hydropower is a clean renewable energy. The development of hydropower cannot only provides sufficient electric energy and brings about comprehensive benefit as well as social benefits with regard to flood control, irrigation, shipping, water supply and tourism, and so on, but also promotes the development of local industry and agriculture, helps save petroleum and coal resources, decreases air pollution and protect environment [9].

Dams have served society for over 4500 years. Through time, functions and uses have been notably altered. Dam functions and their magnitude changed at an accelerating pace once the first hydroelectric dam entered service at Appleton, Wisconsin in 1882 [10]. A hydropower project requires a river. The energy that can be taken from the river will depend on two factors, the volume of water flowing and the drop in riverbed level, normally known as the head of water, that can be used. A steeply flowing river will yield more electricity than a sluggish one of similar size. This does not mean that slow-flowing rivers are not suitable for hydropower development. They often provide sites that are cheap and easy to exploit. In contrast, steeply flowing rivers are often in inaccessible regions where exploitation is difficult. As hydroelectric projects gained growing acceptance as electricity generators and as transmission technology improved, their size sustained notable growth [10]. Hydroelectric projects vary in size and projected functions. Many countries have carried out at least cursory surveys of the hydropower potential within their territory and provisional details of suitable sites are available from the water or power ministries. Sometimes much more detailed information is available but this cannot replace an on-site survey. Indeed surveys carried out as part of a feasibility study form an integral of any hydropower scheme. This article investigates the current status and major challenges for Pakistan in Hydel Power Development.

2. Dams and barrages

Once a site for a hydropower scheme has been identified, there are normally two ways of exploiting it. The first is to build a dam and create a reservoir behind it from which water is taken to drive hydraulic turbines in the project's powerhouse. The second, called a run-of-river scheme, does without a reservoir, though it will usually involve some sort or barrage. Instead it takes water directly from the river to the powerhouse where the turbines are installed.

2.1. Run-of-river project

A run-of-river scheme is the simplest and cheapest hydropower project to develop. Since it requires no dam, a major constructional cost is avoided. Geological problems associated with dam construction (see above) are avoided too. However some sort of diversion structure will be required to direct water from the river into a channel and pipework which will carry the water to the powerhouse. And if, in order to generate a significant head of water, the powerhouse is a long way from the point where the water is taken from the river (the distance can be tens of kilometers in some cases) then the geology of the route will need to be studied carefully too. The simplicity of the run-of-river scheme is attractive but it is also the main weakness of this type of development. With no dam to conserve water, the power plant must rely exclusively on the flow of water in the river. As flow of water in the river fluctuates, so the amount of power that can be generated will fluctuate. Under drought conditions the plant will be able to generate no power, whereas when the river is in flood, much water will have to be allowed to flow past the diversion system without being exploited. Nevertheless this type of project does have significant advantages besides cost, particularly because of the small amount of environmental disruption it causes.

2.2. Reservoir projects

The alternative to the run-of-river is the reservoir project. This will involve a major civil engineering undertaking, construction of a dam. The purpose of a dam is to create a reservoir of water which builds up behind it. Once created, the reservoir allows some measure of control over the flow of water in the river beyond the dam and consequently the flow through the turbines in the powerhouse. Water can be conserved during periods of high flow and used up when rainfall is low. A dam can also be used for flood control.

3. Regional development in hydel sector

Hydropower has played a prominent part in the electrification phase of the industrialization process. As the less industrialized states of the world expand their secondary sector, low cost electricity will be sought to further this phase of domestic change. Economy in investment strategy and the inherent advantage of long term low cost electricity supply and rising urbanization rates use hydropower electricity to service local energy needs. India plans to integrate the national fluvial system by "interconnecting" its key rivers to enhance hydrological management and enlarge its hydropower system by 55,000 MW by 2012. In China hydropower serves as a key link in its evolving energy matrix. Chinese plans call for 158 GW installed in 2010 and 270 GW by 2020. Iran and Turkey pursue a comparable course of action [11].

In 2002 Asia's current installed hydro-capacity was about 225,000 MW, which produced 754,000 GWh/yr. Hydropower supplies more than 50 per cent of electricity in nine countries. Asia continues to be the part of the world with the greatest amount of activity in progress and development in the field of water resources. Nearly 84,400 MW of hydro-capacity is under construction (a large proportion of this being in China). A total of 27 Asian countries have hydro-development in progress, and the countries with more than 1000 MW under construction are: Bhutan, India, Indonesia, Iran, Japan (mainly pumped storage), Kyrgyzstan, Pakistan, Tajikistan, Turkey and Vietnam [12].

India is endowed with rich hydropower potential; it ranks fifth in the world in terms of usable potential. This is distributed across six major river systems (49 basins), namely, the Indus, Brahmaputra, Ganga, the central Indian river systems, and the east and west flowing river systems of south India. The Indus, Brahmaputra and Ganga

together account for nearly 80% of the total potential. In the case of Indus the utilization is, however, governed by the Indus Water Treaty with Pakistan. India ranks fifth in terms of exploitable hydro potential in the world. According to CEA (Central Electricity Authority), India is endowed with economically exploitable hydropower potential to the tune of 148,700 MW. This is distributed across six major river systems (49 basins), namely, the Indus, Brahmaputra, Ganga, the central Indian river systems and the east and west flowing river systems of south India. However, only about 17% of the vast hydel potential has been tapped so far [13,14]. In order to give further fillip for development of hydro sector, the Prime Minister of India announced a 50,000 MW hydro initiative in May 2003. Under this program prefeasibility reports (PFRs) of 162 new projects with an aggregate capacity of 47,930 MW distributed across 16 states was prepared [13].

Indian history in Small hydropower projects (SHPs) developments is more than a century old; the first project of 130 kW was commissioned in the hills of Darjeeling in 1897. This was followed by Sivasamudram project of 4.5 MW in Mysore district of Karnataka in 1902. A 3 MW plant was established at Galgoi in Mussoorie in 1907 and a 1.75 MW plant was established in 1014 at Chaba near Shimla. Some of these nearly 100-year old plants are reported to be still functioning properly [15]. Estimated technical potential of small hydropower (up to 25 MW) in India is about 15,000 MW out of which about 1826 MW has been installed as on December 2006 from 556 projects; in addition, 203 SHP projects with an aggregate capacity of 468 MW are under implementation [15].

SHPs are generally developed in the potential regions by the state renewable energy development agencies. The Ministry of Non-conventional Energy Resources (MNES), which is overseeing the development of small hydropower, has set a target of tapping around 2000 MW till 2012 [13]. India has well-established manufacturing base for small hydro equipment; there are over 8 manufacturers in the country manufacturing/supplying various types of turbines, generators, and control equipment [15].

India has been assisting Nepal in the development of its hydropower potential. Four hydroelectric schemes, namely, Pokhra, Trisuli, Western and Gandhak and Devighat, have been implemented in Nepal with financial and technical assistance from India. The bilateral exchange of power at the borders between the two countries is presently at a level of 50 MW. Untill 2017 Nepal aims to develop 2230 MW of hydropower to meet the projected demand of 2230 MW including 400 MW for export to India. India has had a long association in providing technical and financial assistance to Bhutan in the development of its hydropower resources. Chukha hydropower project (336 MW) has been an important project developed as a joint venture between the Government of India and the Royal Government of Bhutan. About 84% of energy generated from Chukha plant is exported to India. The Kurichu Hydroelectric Project (60 MW) in eastern Bhutan has also been implemented with Indian financial and technical assistance [16].

China's has a large number of rivers, 3886, which have theoretic hydropower reserve of over 10 MW, and more than 50,000 of which cover the basin area of over 100 km^2. The gross theoretical potential exceeds 6000 TWh/yr, its technically feasible potential is put at 2474 TWh/yr while its economically feasible potential has been assessed at 1753 TWh/yr—in all instances, far larger than that of any country in the world [17]. China is paying attention is being focused particularly on the exploitation of hydro-resources in the central and western part of the country to supply power to the east. The Chinese government regards hydropower as the fundamental industry for China's national economy, and is taking a number of steps to stimulate its development. During the past fifty years, On September 26, 2004, by the operation of the first 300,000 kW generator set of Gongboxia Hydropower Station on Yellow River, the gross installed hydropower capacity of China broke through 100 million kW and ranked first in the world. In 2009 the total installed hydropower capacity reached up to 197 GW, in which Three Gorges Dam contributed an installed capacity of 18.2 GW with power generation of 79.85 TW h [9]. Country plans to expand its installed hydropower capacity to 300 million kilowatts by 2015. The amount of China's hydraulic resource ranks first in the world, but the installed hydropower capacity only takes up 26% of technical exploitable hydropower capacity of China; therefore, it has a broad development prospect. The 50-year experience shows that Chinas hydropower construction has attained a quite high technical level, and China has the capability of independently designing and building various hydropower stations under different complex situations [9,18].

Malaysia has a substantial amount of hydropower resources and potential hydropower is estimated at 29,000 MW, however, only around 2091 MW is utilized in 2008 [19–21]. This is basically due to the high capital investment required to develop the hydropower and often involves socio-economic issues. Currently, the biggest hydropower project in Malaysia is the on-going Bakun hydropower project having a capacity of 2400 MW. Bakun dam in Sarawak is one of the largest dams in South-East Asia. Sarawak has abundant hydropower potential which has a total capacity of 108 MW installed in 2009. Sarawak plans to increase hydropower capacity to 3500 MW by 2015 and 7723 MW by 2020. The 2400 MW Bakun scheme is scheduled to begin operation in early 2011 and is followed by the 944 MW Murum dam, 80 km upstream. The plan will reach 6000 MWof hydro installed capacity within 8 years. The Murum dam is already identified to be developed, whereas feasibility studies are being conducted for the Baleh dam (950 MW) and Pelagus dam (770 MW) in the upper reaches of the Rejang river in Sarawak [19].

Turkey has a total hydropower potential of 433 TWh that accounts for almost 1.1% of the total hydropower potential of the world and for 13.75% of European hydropower potential. Only 130 TWh of the total hydroelectric potential of Turkey can be used economically [22]. There were 142 hydro plants in operation in Turkey. These have a total installed capacity of 12,788 MW and an annual average generation capacity of 45.93 TWh, amounting to almost 35.5% of the total exploitable potential, which is at present meeting about 35% of the electricity demand. Forty-one hydro plants with an installed capacity of 4397 MW and an annual generation capacity of 14.351 TWh, which is almost 11.1% of the total potential, are under construction. In the future, 589 more hydropower plants will be constructed to exploit the remaining potential of 69.173 TWh/yr, bringing the total number of hydropower plants to 772 with a total installed capacity of 36,544 MW [23,24].

Greece has, up today, 15 large hydropower stations of total capacity of 2950 MW and almost 50 SHP with total rated power 70 MW. The first two large hydropower stations being in operation since 1954 are of Agras and Louros. Since then, several much larger hydropower stations have been constructed, like the ones of Kremasta (440 MW), and Kastraki (320 MW) in west central Greece. Four large hydropower stations in Greece are located in west Greece and central Macedonia, including the power stations of Kremasta (440 MW), Polifito (375 MW), Kastraki (320 MW) and Pournari-I (300 MW) [25].

Iran also regards hydropower as a priority, as part of its ambitious water resources development program, despite its substantial reserves of oil and gas. Presently, there are 42 operative hydro power plants with total installed capacity of 7672.5 MWand other ones with total capacity of 6650 MW are also under construction. Out of the operative plants, number of big, medium, small and mini/macro plants are 6, 12, 12 and 12, respectively. The big hydro plants, ranging above 100 MW, cover more than 90% of the present installed capacity. In 2007, more than 18,000 GWh of electricity

was fed to national grids. Iran is mostly covered by mountains, therefore, besides having various big and small rivers, there are obviously many water streams which either go waste or terminate at rivers and then connect to sea. Hence, thousands of small and Mini/Macro hydro systems can easily be installed through these streams which can provide locally needed electricity or to be fed to local grids. Presently, there are only 12 small hydro power systems with a total installed capacity of 46.5 MW and 12 Mini/Macro hydro systems with a total capacity of around 2.9 MW [26,27].

Vietnam is another Asian country with vast hydro potential. Vietnam has 2400 rivers 10 km or longer. The hydro energy economic potential is estimated at 84 TWh/yr, which is more than the electricity consumption of 46 TWh in 2005. Current development in 2005 was approximately 4200 MW. Future development planned up to 2025 by Vietnamese agencies 20 GW by 2020 [28]. The Vietnamese Government is also investing in small hydro schemes. Private development is being strongly encouraged, in an effort to meet the country's rapidly increasing demand for power.

Laos—Currently, 12 large and small dams are operational in Laos with combined installed capacity of 1915.6 MW of hydropower. This figure has change dramatically after completion of Nam Theun-2 (1070 MW) which started operation in 2010. Seven projects with combined capacity of 3148.6 MW are under construction. Another 24 project with combined capacity of 6585 MW are in planning stage. Laos has also signed an MOU to provide 7000 MW of electricity after 2015 to Thailand, and 3000 MW of electricity from now until 2020 to Vietnam [29,30]. China and Cambodia are also seeking electricity produced in Laos in the next decade as their economies expand [31].

Bhutan is drained by four major river systems (the Ammochu, the Wangchu, the Sankosh, and the Mansa) with their estimated total length being about 7200 km. Bhutan's gross theoretical potential being assessed at over 263 TWh/yr, with a technically feasible capability of more than 99 TWh/yr (corresponding to a potential generating capacity of around 23,500 MW). Current installed hydro capacity is 1488 MW, having recently been augmented by the commissioning of the 1020 MW Tala HPP, Bhutan's first binational project, developed in conjunction with India. Two more hydro plants are under construction—Punatsangchhu I (1095 MW, for completion by 2015) and Dagachhu (114 MW). The Governments of Bhutan and India are jointly planning to construct a total of ten HPPs, with an anticipated aggregate installed capacity of 11,576 MW, for development by 2020 [17,32].

Sri Lanka has generation capacity of the power system was approximately 1839 MW in 2002, of which utility hydro plants comprised 1172 MW (contributing 2696 GW h of energy), and thermal power comprised 667 MW (contributing 4114 GW h). In addition to these, there were approximately 35 MW of grid connected small hydro plants owned and operated by the private sector [33].

Taiwan has (at the end of November 2009) approximately 1937 MW of the total installed capacity of hydropower, of which 1745 MW is contributed by plants with capacity exceeding 20 MW. Taiwan has hydropower potential of about 22,725 MW and the development proportion of hydropower in Taiwan is very low [34,35].

Tajikistan—Its economically feasible potential is estimated to be 263.5 TWh/yr, of which only about 6% has been harnessed so far [36]. Hydropower provides about 95% of Tajikistan's electricity generation. Installed hydro capacity amounts to about 5500 MW, of which, just over 5000 MW was reported to be operational in early 2009. The principal site is Nurek (3000 MW), which produces approximately 11.2 TWh/yr [17]. The major large hydropower plants in Tajikistan are: Nurek hydropower plant—3000 MW, Sangtuda 1 hydropower plant—670 MW, Baipaza hydropower plant—600 MW, Golovnaya HPP—240 MW and Kayrakkum HPP—126 MW. Small hydropower plants have big prospects, and at present their total capacity is about 115 MW [17].

Kyrgyzstan has several major projects either underway or planned, including three new projects principally for hydro: Naryn I (60 MW), Janikel (130 MW) and Akbulun (100 MW). The national authority predicts a strong future for the development of hydro-resources, as the foundation of development of the country's power sector [12].

Philippines—The Philippines has developed 3367 MW of Hydro powers which will double its hydropower capacity with the addition of 3400 MW. The Philippines has a total untapped hydro power potential of more than 13,000 MW, out of which 85% are classified as large and small hydro, 14% are mini-hydro and 1% are micro-hydro [37].

Viet Nam—Hydropower potential is estimated to be about 20,600 MW across the Mekong and other rivers, of which 4200 MW, or 20% has been developed to date. Currently Viet Nam has more than 50 hydropower stations in operation (10 on tributaries of the Mekong River) and up to 13,000 MW of additional hydropower stations is planned by 2020 [38].

Nepal regards progressive development of its vast hydro-potential as a big priority, and has plans to implement up to 3000 MW by 2016. Technically exploitable capability of county is 44,000 MW. Total hydro capacity at end-2008 was 590 MW, with about 135 MW under construction, including Middle Marsyangdi (70 MW), which entered commercial service in February 2009. [17]. Hydropower & Dams World Atlas (HDWA), 2006 [36] reports that there are 42 small and mini hydro schemes in operation, with an aggregate capacity of very nearly 20 MW. These are run-of-river projects, but the future trend is to be towards storage schemes. Two large-scale schemes being considered for the future are West Seti and Pancheshwar (a binational project to be developed with India), but the main priority will be on small and medium-scale projects. The 144 MW Kali Gandaki 'A' Hydroelectric Project is the largest hydropower project implemented so far in Nepal [39]. Nepal Government has put specific emphasis on the implementation of its National Water Plan (NWP). This plan envisages generating 2100 MW by 2017 and 4000 MW by 2027 [40].

Myanmar has a total installed capacity of only 1335 MW, of which hydropower accounts for about 36%, from about 30 plants built since the 1990s. At least 15 major hydropower plants totalling 10,000 MW are planned to be developed from an exploitable hydropower potential of about 37,000 MW [38].

Developing hydroelectric potential offers many challenges. Public expectations regarding the environmental and social performance of hydropower tend to increase over time. Throughout the world, several projects have recently been the subject of disputes and sharp resistance. This has led in certain cases to the cancellation of major hydropower projects.

4. Hydropower in Pakistan's electricity sector

According to economic survey of Pakistan for 2009–2010 [41] as of March 2010 the installed generating capacity in Pakistan (in utilities) is nearly 20,190 megawatts (MW). This includes thermal (coal, gas and liquid fuel), hydro, nuclear, and renewable based generation. Hydropower constitutes about 6595 MW or 32.5% of total installed capacity of the country. The availability of power had been continually falling short of the demand of 24,474 MW and as a result, the country is experiencing power shortages of varying degrees in different parts of the country [41].

Electricity consumption is measured in kilowatt-hours (kWh). In 2005, the highest per capita use of electricity was in Iceland, where it reached 28057.4 kWh per year. In the United States it is about 13,300 kWh a year; 300 million Americans thus use about

Table 1
National Power Sector Institutions of Pakistan [41,43,44].

Institution/corporate body	Activities and achievements
Ministry of Water & Power [45]	1. Matters relating to the development of water and power resources of the country. 2. Indus Waters Treaty, 1960 and Indus Basin Works. 3. Water and Power Development Authority (WAPDA). 4. Matters relating to electric utilities. 5. Liaison with international engineering organizations in water and power sectors, such as International Commission on Large Dams, International Commission on Irrigation and Drainage, and International Commission on Large Power Systems. 6. Federal agencies and institutions for promotion of special studies in water and power sectors. 7. Electricity. 8. Karachi Electric Supply Corporation and Pakistan Electric Agencies Limited. 9. Matters regarding Pakistan Engineering Council and Institute of Engineers, Pakistan. 10. National Engineering (Services) Pakistan Limited (NESPAK). 11. National Tube well Construction Corporation (NTCC). 12. National Power Construction Corporation (NPCC). 13. Indus River Systems Authority (IRSA). 14. Private Power and Infrastructure Board (PPIB). 15. Electric Utilities. 16. Independent Power Projects. 17. Federal agencies and institutions for promotion of special studies in the water and. 18. Power sectors. 19. Monitoring of technical standards and specifications of materials and tools and plants used in Water and Power engineering and technologies.
Energy Wing—Planning & Development Division [46]	1. Detailed examination of all energy sector projects, finalization of the working papers for the Central Development Working Party (CDWP) and finalization of summaries for Executive Committee of the National Economic Council (ECNEC). 2. Monitoring of the progress of the energy sector projects, identification of issues, discussions with the sponsors of projects regarding issues and suggestions for remedial actions. 3. Appraisal of private sector power projects. 4. To assist the Ministry of Water and Power for preparation of power policy and provide our inputs. 5. Preparation of long term, medium term and short term plans both for conventional and non-conventional energy. 6. Evaluation of the plans and programmes of the energy sector agencies. 7. Preparation, maintenance and operation of the energy planning computer models. Preparation of various scenarios for the analysis of policy options. 8. All matters related to renewable energy.
Private Power & Infrastructure Board (PPIB) [47]	1. The Private Power and Infrastructure Board (PPIB) was created in 1994 to facilitate private sector in the participation of power generation in Pakistan. 2. Act as a one-window organization on behalf of Federal Government ministries, departments and agencies, in matters relating to the establishment of private power projects. 3. Grant consent on behalf of various official agencies in issues related to power, and to review and decide all matters relating to private power projects. 4. Negotiate and finalize implementation agreements and fuel supply agreements with prospective developers; 5. Obtain bank guarantees, performance bonds, letters of credits from private power companies, to receive and (when and if necessary) refund monies relating to the above instruments; 6. Take all other actions as may be required to develop private power in the country; 7. Provide the one-window facility to private sector investor; 8. Provide sovereign guarantee to IPPs on behalf of the GOP; 9. Formulate, review and update the policies relating to private sector investment in power generation; 10. Executes security documents on behalf of the GOP; 11. Liaise with the concerned official agencies for the executing of the projects; 12. Expedite progress of private sector power projects; and 13. Provide necessary information to private sector investors. 14. Acts as a 'one-window' facilitator for conventional private sector power generation projects, including RE hydel projects of more than 50 MW capacity in the country.
Pakistan Water and Power Development Authority (WAPDA) [48]	1. Pakistan Water and Power Development Authority, was created in 1958 as a Semi-Autonomous Body for the purpose of coordinating and giving a unified direction to the development of schemes in Water and Power Sectors. 2. Since October 2007, WAPDA has been bifurcated into two distinct entities, i.e. WAPDA and Pakistan Electric Power Company (PEPCO). 3. WAPDA is now fully responsible for the development of Hydel Power and Water Sector Projects.
National Transmission & Despatch Company (NTDC) Limited [49]	1. Incorporated on 6th November, 1998 and commenced commercial operation on 24th December, 1998. 2. It was organized to take over all the propertise, rights and assets obligations and liabilities of 220 kV and 500 kV Grid Stations and Transmission Lines/Network owned by WAPDA. 3. Operates and maintains nine 500 kV Grid Stations, 4160 km of 500 kV transmission line and 4000 km of 220 kV transmission line in Pakistan.
Pakistan Electric Power Company (Private) Limited (PEPCO) [50]	1. PEPCO is vested with the responsibility of thermal power generation, transmission, distribution and billing. 2. PEPCO has been fully empowered and is responsible for the management of all the affairs of corporatized nine Distribution Companies (DISCOs), four Generation Companies (GENCOs) and a National Transmission Dispatch Company (NTDC). These companies are working under independent Board of Directors.
Karachi Electric Supply Company Limited (KESC) [51]	1. KESC was incorporated in 1913 and is responsible for the generation, transmission and distribution of electricity in Karachi and its adjoining areas. 2. Caters for the electric power requirements of Karachi. 3. KESC is a Joint stock public limited company.

Table 1 (*Continued*)

Institution/corporate body	Activities and achievements
National Electric Power Regulatory Authority (NEPRA) [52]	1. Established in 1997. 2. Since Feb 2007 NEPRA approves Tariff for all Distribution Companies replacing unified WAPDA Tariff. 3. It is Regulatory Authority to oversee the restructuring process and to regulate monopolistic services. 4. Issue Licenses for generation, transmission and distribution of electric power. 5. Establish and enforce Standards to ensure quality and safety of operation and supply of electric power to consumers. 6. Approve investment and power acquisition programs of the utility companies. 7. Determine Tariffs for generation, transmission and distribution of electric power.
Alternative Energy Development Board (AEDB) [53]	1. To develop national strategy, policies and plans for utilization of alternative and renewable energy resources to achieve the targets approved by the Federal Government in consultation with the Board. 2. To act as a forum for evaluating, monitoring and certification of alternative or renewable energy projects and products. 3. To facilitate power generation through alternative or renewable energy resources by: 4. Acting as one window facility for establishing, promoting and facilitating alternative or renewable energy projects based on wind, solar, small-hydel, fuel cells, tidal, ocean, biogas, biomass, etc. 5. Setting up alternative and renewable energy power pilot projects on its own or through joint venture or partnership with public or private entities in order to create awareness and motivation of the need to take such initiatives for the benefit of general public as well as by evaluation concepts and technologies form technical and financial perspective. 6. Conducting feasibility studies and surveys to identify opportunities for power generation through alternative and renewable energy resources. 7. Undertaking technical, financial and economic evaluation of the alternative or renewable energy proposals as well as providing assistance in filling of required licensing applications and tariff petitions to National Electric Power Regulatory Authority (NEPRA). 8. Interacting and coordinating with the National and International agencies for promotion and development of alternative energy. 9. Assisting the development and implementation of plans with concerned authorities and provincial Governments for off-grid electrification.
Pakistan Council for Renewable Energy Technology (PCRET) [54]	1. Established on May 8, 2001. 2. To establish facilities, expertise and to do research, to develop suitable technologies in field of renewable energy. 3. To produce materials, devices and applications in the field of renewable energy. 4. To determine polices and make short and long term programs in field of renewable energy. 5. To promote renewable technologies in the country through research and development. 6. To organize conferences, seminars, workshops for promotion of renewable energy technologies. 7. To establish national and international liaison in the field. 8. To advise and assist the government and relevant industries in the area.
Pakistan Atomic Energy Commission (PAEC) [55]	1. Promotion of and research work on the peaceful uses of atomic energy in the fields of agriculture, medicine and industry. 2. Execution of development projects involving nuclear power stations and the generation of electric power. 3. Programmes to develop nuclear power and fuel-cycle facilities. 4. Promotion of use of radiation and radio-isotopes in agriculture, medicine and industry. 5. Research, development and training of manpower to support the programmes of nuclear power and radio-isotope applications.

400 GW of power. In China the per capita level is 1780.5 kWh, in India 480.5 kWh, Bangladesh 146.5 kWh. The lowest level is in Ethiopia which is 36.3 kWh. World average per capita use of electricity was 2595.7 [42]. In Pakistan Per-capita consumption of electricity was relatively low, of the order of 460 kWh [42].

5. Power sector institutions in Pakistan

The institutional and functional organization of Pakistan's national and regional power sector institutions and departments is depicted in Tables 1 and 2 and Fig. 2.

Administratively hydel potential of Pakistan can be divided into six sectorial regions. Out of total installed capacity 3767 MW is in Khyber Pakhtunkhwa, 1698 MW in Punjab, 1036 MW in AJK and 93 MW in the Northern Areas.

Table 3 shows a list of existing hydropower plants ranging from 1 MW to 3478 MW and Table 4 depicts a comparative summary of the hydel projects in various stages of implementation in various regions of Pakistan. In MTDF it was planned to initiate 23 new hydropower projects during the period, of which 14 will be completed in same period.

6. Hydropower development in Pakistan

Geographically, Pakistan has been blessed with river flows that are naturally supportive to electricity generation. Hydropower development in the Pakistan started in 1925, with the construction of the Renala 1 MW hydropower station. After a decade, the 1.7 MW Malakand-I hydropower station was built, which was later upgraded to a 20 MW capacity. Subsequently, in 1953, the 20 MW Dargai hydropower station was commissioned. At the time of independence, Pakistan inherited a very small power base of only 60 MW for its 31.5 million people. At the time of creation of Water and Power Development Authority (WAPDA) in 1958, the country's total hydel potential capacity was enhanced to 119 MW. By the Indus Water Treaty in 1960, it was decided that Pakistan is entitled to 142 MAF (Indus 93, Jhelum 23 and Chenab 26) of water utilization. Subsequently, 240 MW Warsak, 1000 MW Mangla and 3478 MW Tarbela Hydropower Projects were constructed. Pakistan has an installed hydroelectric capacity of 5928 MW of large (>250 MW), 437 MW of medium (>50 MW and <250 MW), and 253 MW of small to micro (<50 MW) plants, mostly in the northern parts of the country. However, an abundant hydel potential is still untapped which needs to be harnessed. The hydropower potential in Pakistan is over 100,000 MW with identified sites of 55,000 MW [56]. Table 5 elaborates some under going hydro power projects in Pakistan. Various factors such as the dearth of adequately investigated projects, environmental concerns, resettlement and rehabilitation issues, land acquisition problems, regulatory issues, long clearance and approval procedures, power evacuation problems, and in some cases, inter-state issues and law and order problems have contributed to the slow pace of hydropower development. There have been large time and

Table 2
Activities and achievements of regional power sector institutions and departments [43].

Province/region	Corporate body	Activities and Achievements
Khyber Pakhtunkhwa	Sarhad Hydel Development Organization (SHYDO) was established in 1986.	1. Rivers; Bara, Indus, Chitral, Kunhar, Swat, Siran, Kabul, Kohat, Kurram, Tochi, Chitral, Panjkoora and Gabral, Dor, Haroo, Gomal and Zhob. 2. With the assistance of WAPDA and German Technical Assistance Agency (GTZ), prepared a Master Plan for the development of hydro-power potential in NWFP. 3. About 150 potential sites, with a total capacity of 18,698 MW were identified on the basis of high, medium and small head. 4. 17 projects are in operation, 6 sites are under implementation in the public sector and 1 site has been offered to the private sector.
Punjab	Punjab Power Development Board was created in the Irrigation Department in 1995	1. Rivers: Sutluj, Ravi, Chenab, Jhelum and Indus. 2. Promotion of hydel power generation on canal sites in Punjab. 3. At different canals, about 324 potential sites of medium and low head, with a total estimated capacity of 5895 MW were identified. Recently, WAPDA has launched the 1450 MW Ghazi Barotha hydel project as a run-of-river project.
Azad Jammu & Kashmir	Government of AJK (GOAJK) established the AJK Hydro Electric Board (HEB) in 1989	1. Rivers: Jhelum, Poonch and Neelum and their tributaries. 2. AJK HEB successfully completed the 1.6 MW. 3. Kathai, 2 MW Kundel Shahi, 2 MW Leepa, and 30.4 MW Jagran hydel power projects. 4. A number of hydel projects with the total capacity of 829 MW are being processed/undertaken by the private sector.
	GOAJK created the AJK Private Power Cell (PPC) in 1995.	
Northern Areas	Northern Areas Public Works Department (NAPWD)	1. Rivers: Gilgit, Naltar, Boladas, Hunza, Hushe, Thalle, Ishkuman, Ghizar Khunjarab, Nagar, Kilik, Yasin, Kharmang, Karambar, Ishkoman, Phakora, Hayal, Shyok, Braldu, Bashu, Shigar, Indus, Astore and their tributaries. 2. Currently only 40% of the local population of Northern Area has been provided with electrical power. 3. An 18 MW Naltar-III Hydropower Project is under implementation in public sector.
Sindh	Irrigation & Power Department	1. Rivers: Indus, Gaj. 2. Six potential sites of an estimated total capacity of 178 MW have been identified with medium and low head at different canals. The hydropower projects identified in the Province are Nai Gaj Fall, Sukkur (Indus/Nara Canal), Rohri canal and Guddu Barrage Projects. 3. These projects have an estimated 178 MW capacity. 4. Feasibility studies of the Rohri and Guddu Barrage Projects have been completed, and it is expected that implementation work will be started in the near future. 5. Presently, no hydel projects are in operation or under implementation, either in the public or private sectors.
Balochistan	National Water Resources Development Programme	1. Rivers: Dasht, Basol, Hingol, Hub, Mula, Sukleji, Winder, 2. Included 8 irrigation projects, but none of them have the required head to generate electricity. 3. Presently, no hydel. 4. Projects are in operation or under implementation in the public sector, and no projects are being processed/undertaken by the private sector.

Table 3
Existing hydel power stations in Pakistan [44].

S.No	Name of Project	Installed capacity (MW)
1	Tarbela	3478
2	Ghazi Barotha	1450
3	Mangla	1000
4	Warsak	240
5	Chashma	184
6	Malakand	19.6
7	Dargai	20
8	Rasul	22
9	Shadiwal	13.5
10	Chichoki Malian	13.2
11	Nandipur	13.8
12	Kurram Gari	4
13	Reshun	2.8
14	Renala	1.1
15	Chitral	1
16	Jagran-I	30.4
17	Kathai	1.6
18	Kundel Shahi	2
19	Leepa	1.6
20	Northern Area	94
21	Small/Micro Hydel Stations	3
	Total	6595.032

cost overruns in case of some projects due to geological surprises, resettlement and rehabilitation issues, etc. Over past three decades construction of new dams on Indus River system has particularly been a major source of conflict between the upper and lower riparian. The lower riparian Sindh province has been strongly opposing new dams on Indus. One major argument of Sindh against the big dams has been socio-environmental impacts on the province especially on flood plains and delta.

Many economically feasible hydropower projects are financially challenged. High up-front costs are a deterrent for investment. Also, hydro tends to have lengthy lead times for planning, permitting, and construction. When life-cycle costs are examined, however, hydro often has the best performance, with operating costs being low in comparison with the capital investment. The development of more appropriate financing models is a major challenge for the hydro sector, as is finding the optimum roles for the public and private sectors [57].

7. Government's policy initiatives

Considering the large potential and the intrinsic characteristics of hydropower in promoting the country's energy security and

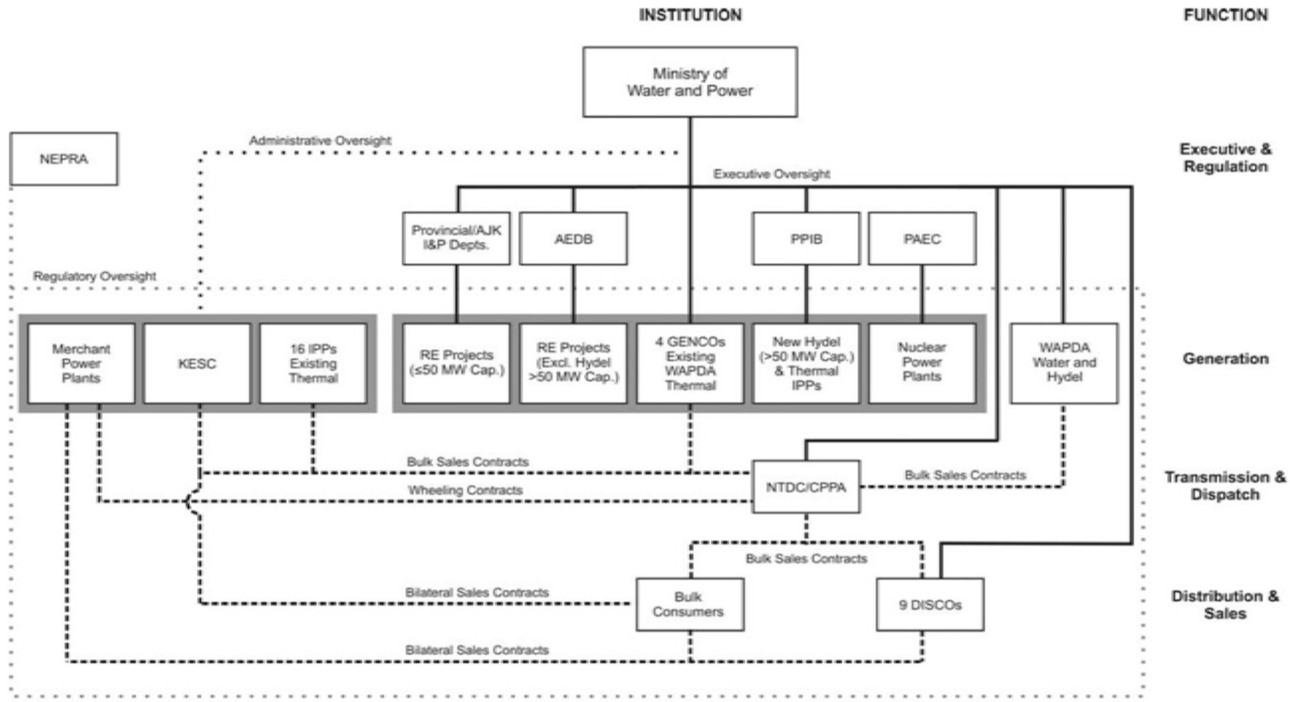

Fig. 2. The institutional and functional organization of Pakistan's power sector [43].

flexibility in system operation, government is tried to accelerate hydropower development through number of policy initiatives. The government of Pakistan announced power policies in 1994, 1998 and 2002 and Hydel Power Policy 1995 with the objective of meeting future energy demand and attracting the Foreign Direct Investment in the Energy Sector through the private sector involvement. The salient features of the "Policy for Power Generation Projects 2002" devised to accelerate the development of generation capacity through Private Sector resource mobilization is as follows [43,58]:

1. Hydel projects to be implemented on a Built-Operate-Transfer (BOOT) or Build-Own-Operate (BOO) model.
2. The basis for selection of private power project is a minimum levelized tariff.
3. Detailed feasibility studies for a particular site-specific hydel or indigenous coal based projects to be prepared before bids were invited.
4. The Government of Pakistan (GOP) guaranteed the terms of executed agreements, including payment terms.
5. Companies to be operated according to the applicable laws of Pakistan.
6. For hydel and indigenous fuels and renewable projects, unsolicited proposals to be permitted from sponsors in the absence of feasibility studies for the projects.
7. One-window facility will be provided at federal level by Private Power and Infrastructure Board (PPIB) for all projects above 50 MW capacity.
8. Provinces can manage the investment for projects up to 50 MW capacity.
9. For projects above 50 MW, the provinces would be the main drivers and catalysts for marketing and coordinating projects with PPIB.
10. Exemption from income tax including turnover tax and withholding tax on imports; provided that no exemption from these taxes will be available in the case of oil-fired power projects.
11. Exemption from Provincial and local taxes and duties.
12. The ownership of hydel projects would be transferred to the GOP at the end of concession period.
13. For projects with a capacity above 50 MW power purchaser will bear the risk of availability of water (Table 6).

To further encourage the hydel and coal based power projects in the country, the government has allowed 17 percent internal rate of return (IRR) to hydel and indigenous coal and 16 percent to

Table 4
Comparative summary of the hydel projects in various stages of implementation in various regions of Pakistan [44].

Region	Projects in Operation (MW)	Public sector Projects (MW)	Private sector Projects (MW)	Projects with feasibility study (MW)		Projects with pre-feasibility study/raw sites (MW)	
				Above 50 MW	Below 50 MW	Above 50 MW	Below 50 W
Khyber Pakhtunkhwa	3767.2	635	84	58	143	13584	426
Punjab	1698	96	Nil	3720	32.17	NIL	349.65
AJK	1036.1	973.8	828.7	420	48.2	1152	177
Northern Areas	93.732	18	Nil	505	71.5	10905	814
Sindh	Nil	Nil	Nil	Nil	49.5	80	48.55
Baluchistan	Nil	Nil	Nil	Nil	0.5	Nil	Nil
Total	6595.032	1722.8	912.7	4703	344.87	25721	1815.2

Table 5
Under construction hydropower projects in Pakistan [56].

Sr #	Name of Project	Hydropower (MW)	Progress/Completion
1.	Mangla Dam Raising Mirpur, AJK	Addition 644 GWh	Substantially completed
2.	Gomal Zam Dam FATA	17.4	65% (Dec 2010)
3.	Satpara Dam Gilgit Baltistan	15.8	91% (Dec 2010)
4.	KHAN KHWAR Besham, KPK	72	97% Dec 2010
5	DUBER KHWAR Kohistan, KPK	130	77% (Aug 2011)
6.	ALLAI KHWAR–Battagram, KPK	121	54% (Oct 2011)
7.	JINNAH HYDROPOWER, Jinnah Barrage	96	95% (Jun 2011)
8.	NEELUM JHELUM Neelum, AJK	969	16% (Oct 2015)
	Total	1421.2	

imported coal power projects as against the 15 percent IRR for oil and gas based thermal power projects.

In 2006, government announced Policy for Development of Renewable Energy. The Strategic Policy Objectives of "Policy for Development of Renewable Energy for Power Generation-2006" [43] are described below as subsections.

7.1. Energy security

Mainstreaming of renewable energy and greater use of indigenous resources can help diversify Pakistan's energy mix and reduce the country's dependence on any single source, particularly imported fossil fuels, thereby mitigating against supply disruptions and price fluctuation risks. Additional costs and risks relating to fuel stocking, transportation, and temporary substitute arrangements are also irrelevant for RE systems, except for backup purposes.

7.2. Economic benefits

When properly assessed for their externalities, renewable energy options can become economically competitive with conventional supplies on a least-cost basis. This is particularly true for the more difficult, remote, and underdeveloped areas, where RE can also have the greatest impact and the avoided costs of conventional energy supplies can be significant. RE can thus supplement the pool of national energy supply options in Pakistan, expediting economic empowerment, improving productivity, and enhancing income generating opportunities—especially for currently marginalized segments of the population. Decentralized RE systems can also help reduce energy distribution losses and result in system-wide and national efficiency gains (e.g., as measured by 'energy intensity', or energy use per unit of GDP). A growing renewable energy industry can afford new prospects for employment and business opportunities amongst local manufacturers and service providers.

7.3. Social equity

Pakistan's present low per-capita consumption of energy can be elevated through greater RE use. Issues relating to social equity—such as equal rights and access for all citizens to modern energy supplies, improved human development indicators, poverty alleviation amongst deprived sections of society, and reduced burden on rural women for biomass fuel collection and use—can also be addressed significantly through widespread renewable energy deployment. RE can thus facilitate social service delivery and help improve the well-being of the country's poorest, which presently have little or no access to modern energy services.

7.4. Environmental protection

Local environmental and health impacts of unsustainable and inefficient traditional biomass fuels and fossil fuel-powered electricity generation can be largely circumvented through clean, renewable energy alternatives. Similarly, displaced greenhouse gas emissions carry significant global climate change benefits, towards which Pakistan has pledged.

Specific goals of the renewable energy policy is to increase the deployment of renewable energy technologies (RETs) in Pakistan

Table 6
Hydrology Risk Allocation Matrix [43].

Hydro Variation	Availability Status*	Risk Mitigation
a. Actual water flow/month less than the Mean Flow/Month	1. Capacity of the hydroelectric IPP available is equal to the Mean flow Capacity level. 2. Capacity of the hydroelectric IPP is not available wholly or partially (i.e., is less than Mean Flow Capacity)	1. Hydroelectric IPP will be paid for energy generation corresponding to Mean Flow (i.e., the power purchaser absorbs the loss). 2. Hydroelectric IPP is not paid to the extent that capacity is not available.
b. Actual water flow/month more than the Mean Flow/Month	1. Capacity of the hydroelectric IPP available is equal to the Mean Flow Capacity level. 2. Capacity of the hydroelectric IPP is not available wholly or partially (i.e., is less than Mean Flow Capacity)	1. Hydroelectric IPP will be paid for energy generation corresponding to 'Mean Flow Plus' (i.e., Mean Flow Energy production plus 10% of the value of energy generated above the mean flow; e.g., if the tariff is Rs p/kWh, then the production up to the Mean Flow Energy Production level will be paid at the rate of Rs p/kWh, and any additional production will be paid at the rate of 0.1 x Rs p/kWh) as a production bonus, so that both the producer and purchaser share the benefit of increased production -Hydroelectric IPP is paid equal to the actual energy generation up to the Mean Flow Energy Production level only.
c. Actual water flow/month equal to the Mean Flow/Month	1. Hydroelectric IPP is available equal to the Mean Flow Capacity level. 2. Capacity of the hydroelectric IPP is not available wholly or partially (i.e., is less than Mean Flow Capacity)	1. Hydroelectric IPP will be paid for the energy generation corresponding to the Mean Flow Energy Production. 2. Hydroelectric IPP will be paid equal to the actual energy generation up to the Mean Flow Energy Production level only.

so that RE provides a higher targeted proportion of the national energy supply mix, i.e., a minimum of 9700 MW by 2030 [43].

8. Large hydropower in Pakistan

Dam size increases have been accompanied in most cases with proliferation of multiple functions, such as irrigation, urban water supply, energy, flood control, navigation, recreation and fishing as the more widespread uses. The idea of the dam has sustained notable changes and varied metamorphoses. It is hydroelectric dams that gradually attracted most of the negative attention, partly the result of their size impacting upon riverine settlements that were forced to relocate. Moreover, the electricity was consumed in distant population poles without contributing to the standard of life whence the electricity originated. Key objections centered on forced human resettlement, which must be seen as traumatic for indigenous peoples as well as for old settlements as noted in Kalabagh Dam Project. According to Onat and Bayar, 2010 the land amount used by production technologies per unit energy is an important sustainability indicator. The renewable energy technologies, mainly hydroelectric systems, have to compete against to claims that they frequently use and destroy agricultural lands and give harm to biological variety.

The large dams and reservoirs require lengthy and costly planning and construction, as well as the relocation of people from the reservoir area. In the past few decades, millions of people have been relocated in India and China. Dams have ecological effects on the ecosystems upstream and downstream, and present a barrier to migrating fish. Sediment build-up can shorten their operating life, and sediment trapped by the dam is denied to those downstream. Biomass that decomposes in reservoirs releases methane and carbon dioxide, and in some cases these emissions can be of a similar order of magnitude to those avoided by not burning fossil fuels. Climate change could itself limit the capacity of dams in some areas by altering the amount and pattern of annual run-off from sources such as the glaciers of Tibet [4].

Governments change, electricity needs shift, and increase but the basic physical conditions tend to retain their physical characteristics for a predictable time span. Large hydropower projects have a number of social, political and technical issues associated with them. Construction of barrages and dams upstream on the Indus has degraded the Indus delta. Despite the government's fear based campaign to achieve consensus on the construction of the Kalabagh dam, it has failed to remove the apprehensions of Sindh and the Khyber Pakhtunkhwa [59].

The promise of cheap hydro energy from large dams if analyzed through the sustainable development prism is not reliable because of two reasons. First, there is a vocal demand to include the social displacement and environmental degradation costs in the upfront capital costs of such projects. The financing of such mega projects remains the most important part of this problem. Funding from international donors for such a project is difficult to obtain, considering their commitment to facilitate investments in private thermal-based power plants. Second, even if the government arranges funding for such projects, the outlays involved in resettlement compensations are huge. For example, the government intends to spend $ 33.2 billion on the resettlement issues of the Kalabagh dam by constructing 20 model and 27 extended villages [59].

9. Small hydropower in Pakistan

SHP is an alternative that has emerged as a preferred option, especially for hilly terrain where natural and manageable waterfalls are abundantly available. SHP potential is often assessed separately from large-scale hydro potential. Hydropower has various degrees of 'smallness'. To date there is still no internationally agreed definition of 'small' hydro; the upper limit varies between 2.5 and 25 MW. A maximum of 10 MW is the most widely accepted value worldwide, although the definition in China stands officially at 25 MW. In the jargon of the industry, 'mini' hydro typically refers to schemes below 2 MW, micro-hydro below 500 kW and pico-hydro below 10 kW [5]. These are arbitrary divisions and many of the principles involved apply to both smaller and larger schemes. In Pakistan there is no clear definition of SHP, however Power Generation Policy, 2002 has entrusted provinces to manage investments up to 50 MW power projects.

The cost of SHP projects depends on where they are set up, i.e. the location and the site's topography. The cost of the civil works and the equipment usually determine the cost of the project, however, they are about five times more expensive and harder to scale than larger schemes. They normally cost between $1 million to about $1.4 million per MW [60]. Pay-back period of these projects is usually 5–7 years and this depends on the capacity utilization factor.

It can be one of the most reliable and economic methods of generating electricity. Its power profile allows it to immediately respond to fluctuations in demand, and address both base-load and peak load demand. A well-designed SHP system can blend in with its surroundings and offer very low environmental impact. SHP schemes are mainly run-of-river with little or no reservoir impoundment.

SHP installations are usually "run of the river" plants, which means that there is no water storage. The water has to be lead through the hydro turbine right away or it will be lost. The capacity of the power plant will decide how much of the inflow to utilize. The civil works purely serve the function of regulating the level of the water at the intake side of the hydro-plant. Therefore run-of-river installations do not have the same kinds of adverse effect on the local environment as large hydro [5]. Uncertainty in the future power prices and variation in the water inflow over the year and from one year to another complicates this capacity choice [61].

Head height is an important factor in determining small hydro economics with higher head sites generally cheaper to develop. An impulse turbine is the best choice where the head height is above 30 m, a reaction turbine below for lower heads. A head height of less than 2.5 m is difficult to exploit. The following sectors within SHP show important potential for growth:

- New low-head SHP scheme;
- Mini- and micro-hydropower;
- Repowering and upgrading of existing sites;
- Development of pumped-storage facilities.

The quantity and quality of energy services required in the mountains is quite low due to the scattered settlement pattern and lack of infrastructure development and diversification of economies. At the same time, the extension of grid electricity in the mountain areas is not economically feasible. Where line extensions are installed in rural areas, those are characterized by poor reliability and high line losses. Line extensions are often awarded as political favors, leading to inefficient service area growth. Metering individual customers is prohibitively costly in rural areas, and customers are charged a flat rate (or not billed at all), leaving no incentive to conserve electricity. It is desirable to take into consideration of mountain specificities such as inaccessibility, fragility, marginality and diversity as it provides conditions for feasibility and suitability of certain types of energy technologies [62]. These arguments, together with the fact that mountains are extremely scale sensitive due to their fragile nature, make small hydro and

micro-hydropower as one of the suitable options among various options available for the provision of energy in rural mountain areas. Also, the small-scale interventions in mountain communities are also less risky compared to large-scale interventions, be they road or dam construction [63]. Akorede et al., 2010 [64] suggested distributed generation that feed on renewable energy sources would not only help meet the growing energy demand but also preserve our environment from the devastating effects of GHGs caused by the traditional method. Interestingly, scientists and experts in industries have estimated that the available renewable energy sources can meet the requirement of the future global energy demand. Study has also identified four areas where distributed generation (DG) could be of significant use in mitigating these environmental problems, thereby improving the air quality. The areas are: reduction in GHG emissions, higher energy efficiencies, reduced damages to human health, and conservation of resources for additional use. SHP stations are also a powerful tool for local and sustainable development since that enable local businesses to participate in the installation, renovation and maintenance of the SHP.

10. Mini and micro hydropower project in Pakistan

According to a United Nations Development Programme (UNDP)/World Bank definition, a project in the range 1–100 kW is classified as a micro project while 100 kW to 1 MW is a mini project. Myths, Pros and Cons of Micro Hydro Power are discussed in Table 7.

Where there is a suitable site pico hydropower is usually the lowest cost option for off-grid rural electrification, and is environmentally sustainable. The technology has been developed for a wide range of site conditions, but the design, even for such small schemes, is usually site specific. In order to achieve low installation cost per unit power output, and hence low energy costs, it is necessary to select the components of the scheme to reduce cost and increase efficiency [65,66].

The small scale renewable generation may be the most cost-effective way to bring electricity to remote villages that are not near transmission lines. In the new millennium demand for electricity is expected to increase more rapidly than demand for other forms of energy. Within the range of small hydropower, minihydro typically refers to schemes below 1 MW, microhydro to below 100 kW and pico-hydro to below 5 kW. Although all of these technologies could be regarded as small hydropower, they have specific technical characteristics that warrant their own definition. Generally micro- and pico-hydro technologies are used in developing countries to provide electricity to isolated communities where the electricity grid is not available, whereas mini-hydro tends to be grid-connected. In most cases, no dam or reservoir storage is involved in pico-, micro- and mini-hydro schemes. Fig. 3 shows community based micro-hydal plant at Chokana, Balakot. 15 kV micro-hydal plant started supply of electricity to 58 households. The project cost was 8750 USD with 10% community share. The economic success of these early micro-hydro schemes depended largely on achieving a high load factor and using the scheme for income-generating activities The first expressed demand for power is usually domestic lighting (plus TV and radio), but lighting alone is rarely enough to justify a new micro-hydro plant because the load factor rarely exceeds 10% and further demand only builds up slowly (typically less than 20%/year). Increasing commercial and industrial end-uses, i.e. raising the productivity of local labor, is the most direct way of justifying a new scheme on economic grounds. Hence if lighting is wanted by night, then this must be 'paid for' by using hydropower for productive activities by day. Studies in Nepal have shown that rural electrification alone has had minimal impact on agricultural or industrial production. The most cost-effective use of hydropower in Nepal has been through mechanical end-uses [5].

Rural electrification programs involving renewable energy technologies usually involve consumers who have low-incomes, who cannot afford to pay for technologies with high initial capital costs by themselves. In rural areas, the consumers are also scattered over large areas and therefore the additional expense of distribution networks and the high transaction costs for small decentralized systems add to the burden. The demand and use of electricity in rural areas is also low and this makes it less profitable for private companies to offer their services.

Governments of developing countries are known to make commitments based on political interest and these interfere with systematic development of such programs as the electrification plans can be altered by the politicians at any time according to their interests. In fact, Pakistan Council of Renewable Energy Technologies (PCRET) has implemented 290 micro-hydro power schemes in the Federally Administered Tribal Area (FATA, part of the Khyber Pakhtunkhwa) and the Northern Areas (part of Kashmir), with a total capacity of 3.5 MW, ranging from 3 to 50 kW per plant, with the participation of the local community. All of these plants are run-of-river type in the low (4 m) to medium (30 m) head range. Similarly, Aga Khan Rural Support Program (AKRSP) has constructed 171 micro-hydro units providing electricity to around 17,000 households in the remote and isolated region of northern Pakistan, and currently provides 11,000 households with electricity in very remote locations [67]. PCRET has set target for installing 20 MW Micro-hydel Plants in Gilgit Baltistan, AJK & Khyber Pakhtunkhwa and Canal-falls to electrifying 100,000 houses by 2020 [54].

Numerous promising hydel potential sites have been identified in the Northern Areas, but, due to the absence of high power transmission lines, these sites have not been developed so far. On account of difficult mountainous terrain and the non-availability of high power transmission line system, the Northern Areas are not connected to the National Grid and no projects have been undertaken by private investors.

These plants not only provide electricity for light at night but are also used to run small industrial units such as flour mills for threshing wheat and maize, and ginning cotton during daytime when electricity is not required for lighting. Once the plant is installed, the local community takes the operating responsibility. Recently, UNDP, AEDB and GTZ launched a project to promote micro-hydro energy for the poor rural communities in the Northern Areas not connected to the national electricity grid. The areas are remotely located at a considerable distance from the national grid. Hence micro-hydropower plants are the most attractive option for power generation. The system is a decentralized one, with no dependence on the national grid.

A major advantage of micro-hydro is that it can be built locally at a relatively low cost. For instance, imported turbine sets generating up to 50 kW cost approximately $ 500–1000 per kW, while the local manufacturers offer facilities for turbine-manufacturing at $ 170–250 per kW, with marginally reduced turbine efficiencies [67]. The cross-flow turbine used by PCRET and AKRSP were manufactured in local workshops.

The costs of local manufacture can be reduced further by developing local engineering capabilities and advisory services. Unfortunately the turbine used by PCRET and AKRSP is manufactured in local workshops having no design or quality control facilities. In order to accelerate the development and enhance the performance of small hydro power in the country, it is imperative to benchmark the work of the SHP industry to identify, understand and adapt the proven best practices of the world leaders in the industry. As the huge potential of hydro power remains as yet untapped, there is a great potential for benchmarking in the SHP industry in Pakistan.

Table 7
Myths, pros and cons of micro hydro power.

Misconceptions	Advantages	Disadvantages
Small streams do not provide enough force to generate power-The Truth: Energy output is dependent on two major factors: the stream flow (how much water runs through the system) and drop (or head), which is the vertical distance the water will fall through the water turbine.	***Efficient energy source:*** It only takes a small amount of flow (as little as two gallons per minute) or a drop as low as two feet to generate electricity with micro hydro. Electricity can be delivered as far as a mile away to the location where it is being used.	***Suitable site characteristics required:*** In order to take full advantage of the electrical potential of small streams, a suitable site is needed. Factors to consider are: distance from the power source to the location where energy is required, stream size (including flow rate, output and drop), and a balance of system components — inverter, batteries, controller, transmission line and pipelines.
Large water reservoir is required-The Truth: Most small-scale hydro systems require very little or no reservoir in order to power the turbines. These systems are commonly known as 'run-of-river', meaning the water will run straight through the generator and back into the stream. This has a minimal environmental impact on the local ecosystem.	***Reliable electricity source:*** Hydro produces a continuous supply of electrical energy in comparison to other small-scale renewable technologies. The peak energy season is during the winter months when large quantities of electricity are required.	***Energy expansion not possible:*** The size and flow of small streams may restrict future site expansion as the power demand increases.
Hydro generators will damage the local ecosystem-The Truth: Careful design is required to ensure the system has a minimal impact on the local ecology. A small amount of energy compromise may result, but this will ensure that the project does not have an effect on local fish stocks. The Environment Agency requires that stream levels must be maintained at a certain level in order to sustain the life within. Since there is no loss of water in the generation process, these requirements can easily be met.	***No reservoir required:*** Microhydro is considered to function as a 'run-of-river' system, meaning that the water passing through the generator is directed back into the stream with relatively little impact on the surrounding ecology.	***Low-power in the summer months:*** In many locations stream size will fluctuate seasonally. During the summer months there will likely be less flow and therefore less power output. Advanced planning and research will be needed to ensure adequate energy requirements are met.
Micro hydro electricity is unreliable-The Truth: Technology advances (such as maintenance-free water intake equipment and solid-state electrical equipment) ensure that these systems are often more reliable in remote areas. Often these systems are more dependable than the local power main.	***Cost effective energy solution:*** Building a small-scale hydro-power system can cost from $1,000–$20,000, depending on site electricity requirements and location. Maintenance fees are relatively small in comparison to other technologies.	***Environmental impact:*** The ecological impact of small-scale hydro is minimal; however, the low-level environmental effects must be taken into consideration before construction begins. Stream water will be diverted away from a portion of the stream, and proper caution must be exercised to ensure there will be no damaging impact on the local ecology or civil infrastructure.
The electricity generated is low quality-The Truth: If the latest electronic control equipment, inverters and alternators are used, the resultant power supply has the potential to be of higher quality the main electrical power grid.	***Power for developing countries:*** Because of the low-cost versatility and longevity of micro hydro, developing countries can manufacture and implement the technology to help supply much needed electricity to small communities and villages.	
Hydro power is free-The Truth: Micro power development can be cost-intensive to build and maintain. There are some fixed maintenance costs. These costs vary according to site location and material requirements.	***Integrate with the local power grid:*** If your site produces a large amount of excess energy, some power companies will buy back your electricity overflow. You also have the ability to supplement your level of micro power with intake from the power grid.	

SHP is a renewable energy source, a proven technology that can be connected to the main grid, used as a stand-alone option or combined with irrigation systems. More than 1000 MW of micro/mini hydropower potential is available in the northern mountainous region of the country [68]. The development of micro hydropower plants should continue, with continuous research for increasing the efficiency of these plants.

AEDB is actively working to install 103 micro hydro power plants at Chitral and other places in Gilgit Baltistan. The total cost of the project is US$ 19.5 million out of which US $ 1.0 million is for Productive Use of Renewable Energy (PURE). Eight micro/mini/small hydel power projects have been initiated under the Renewable Energy Development Sector Investment Program of Asian Development Bank (ADB). The cost of these eight projects is estimated at US $ 139.5 million. Furthermore, Government of Punjab issued letter of intents (LOIs) to 10 private investors for establishment of small hydel power project with a cumulative capacity of 142 MW at different location of Punjab [41].

In northern Pakistan alone there is an estimated potential of 300 MW for micro hydropower plants with installed capacities below 100 kW each, however only about 10 MW of that potential had been tapped by a total of some more than 300 projects co-financed by AKRSP, PCRET, European Union (EU) and private developers. Now, with the assistance of the Asian Development Bank and within the scope of Malakand Rural Development Project, 100 micro hydropower plants with ratings ranging from 5 to 50 kW are under implementation with in and around Malakand Division of the Khyber Pakhtunkhwa [68].

In order to facilitate development and generation of alternate or renewable energy to achieve sustainable economic growth with transfer of technology, Government of Pakistan established Pakistan Council of Appropriate Technology (PCAT) in 1975, National institute of Silicon Technology (NIST) in 1981 and AEDB in 2003. In May 2001 NIST and PCAT merged to become Pakistan Council of Renewable Energy Technologies (PCRET) thus having two main departments, AEDB and PCRET, in government sector for execution and implementation of renewable energy projects [69].

National policy for permitting standalone systems including renewable system for rural areas implies making it easier for private investment to set up these projects and promoting such projects in general. Shah et al., 2011 [70] suggested that national educational policies must be redesigned in such a way that they must

Fig. 3. Community based micro-hydal plant Chokana, Balakot.

be supportive to national science and technology policies to create awareness regarding sustainable development through RE. The weaker impact of National Science and Technology Policies, and traditional educational system (more precisely the technical education) towards sustainable development is due to lesser focus on community participation to achieve this cause. Therefore to avoid such policy dilemmas for sustainable development more importance needs to be given to community participation for the promotion of sustainable development concepts through RE. Same study recommends technical education infrastructure can be efficiently utilized to promote the concept of sustainable development through the introduction of courses dealing with renewable energy technologies.

11. Conclusion

Hydropower has played a prominent part in the electrification phase of the industrialization process. As the less industrialized states of the world expand their secondary sector, low cost electricity will be sought to further this phase of domestic change. Economy in investment strategy and the inherent advantage of long term low cost electricity supply and rising urbanization rates use hydro powered electricity to service local energy needs.

Pakistan has substantially stepped up its efforts to the hydro sector, support from international agencies and the private sector is also needed. In case of such projects, the developers however seem to have a perception that the appraisal processes are often long and this in turn could cause delays in taking up the project for implementation and consequential time and cost overruns. Hence they hold the view that in case of projects that are in a fairly mature state for taking up for implementation, it may be prudent to borrow from the market (especially when such funding can be accessed). Nevertheless, the developers consider that working with international donor agencies would provide some rich experience and also improve their credit rating with other financiers.

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